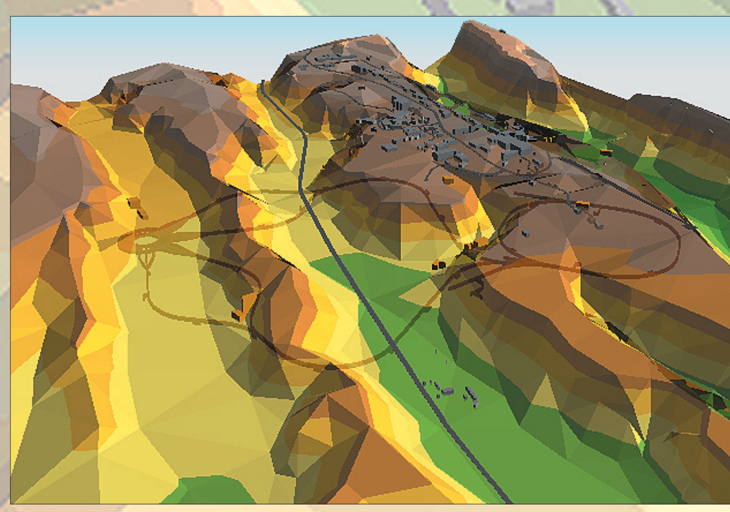


Construction of a New Isotope Production Facility

R.C. Heaton, E.J. Peterson (C Division)

Radioisotopes, which are radioactive nuclei of specific chemical elements, are useful tools in medicine and research. Radioisotopes introduced into the body are taken up in different amounts by different organs and can be used for diagnosis and treatment of diseases. Recording the distribution and concentrations of such radioisotopes as they decay provides clinicians with information about the presence, size, and shape of various abnormalities in body organs. Iodine-131, for example, is used to locate brain tumors, measure cardiac output, and determine liver and thyroid activity. Rubidium-82 is used in cardiology diagnosis. Aluminum-26 is used in biological studies into the causes of Alzheimers' disease and in material-science experiments. Silicon-32 is used to study nutrient metabolism in phytoplankton, most notably the diatom, which is a type of algae that researchers believe plays a major role in influencing climate change. In industry, radioisotopes of various kinds are used to measure the thickness of metal or plastic sheets and to examine manufactured metal parts for structural defects. Other important isotopes used in biomedical, industrial, environmental, physics, and material-science research include arsenic-73, beryllium-7, bismuth-207, cadmium-109, gadolinium-148, niobium-92, rubidium-83, selenium-72, technetium-95m, titanium-44, vanadium-48, vanadium-49, yttrium-88, zinc-65, and zirconium-88.

The new Isotope Production Facility (IPF) at the Los Alamos Neutron Science Center (LANSCE) will make possible a year-round, uninterrupted supply of these and many more important radioisotopes. Construction of the IPF, which represents a $20 million investment by the Department of Energy (DOE) in the radioisotope program at Los Alamos National Laboratory (LANL), is currently 80% complete. The new IPF will become operational in 2003.

New Target Irradiation Capability at LANSCE

The LANL radioisotope program has been one of the most successful and visible ongoing endeavors in the production and distribution of isotopes nationwide. The national health-care system depends on LANL's ability to deliver key medical radioisotopes to customers on a year-round daily basis. LANSCE has supported the program by producing radioisotopes for more than twenty years. Without the production capabilities at LANSCE and other national and international facilities, DOE could not meet the needs of its radioisotope customers. More than a billion dollars of installed and operational medical instruments that depend on these radioisotope supplies would be adversely impacted if these materials were not made available.

The production of radioisotopes at LANSCE traditionally took place when excess beam from the accelerator was used to irradiate targets near the beam stop in experimental Area A. However, a changing mission and a new experimental program at LANSCE has ended beam delivery to Area A. Thus, radioisotope production at that location is no longer possible. Meeting the continuing demand for radioisotopes from industry, research institutions, the medical community, academia, and government therefore required the design and construction of a new production facility elsewhere at LANSCE (Fig. 1). The completion and commissioning of this new target irradiation facility, when combined with similar isotope-production capabilities at other locations, will ensure a dedicated year-round supply of radioisotopes.

The main systems of the new IPF will include upper- and lower-level building structures to house special IPF equipment, a new beam line from the existing accelerator to the target area in the lower level of the facility, target equipment, and a hot cell in the upper level of the facility to handle the irradiated targets. The scope of this project includes the design and construction of a beam tunnel and targeting area, the design and construction of an upper-level building to house mechanical and remote-handling equipment, the design and construction of an accelerator beam line, the modification of one segment of the LANSCE accelerator, and the design and construction of target-irradiation and remote-handling systems. When complete, the IPF will follow an operating sequence that begins with loading targets into the target chamber and ends with shipping

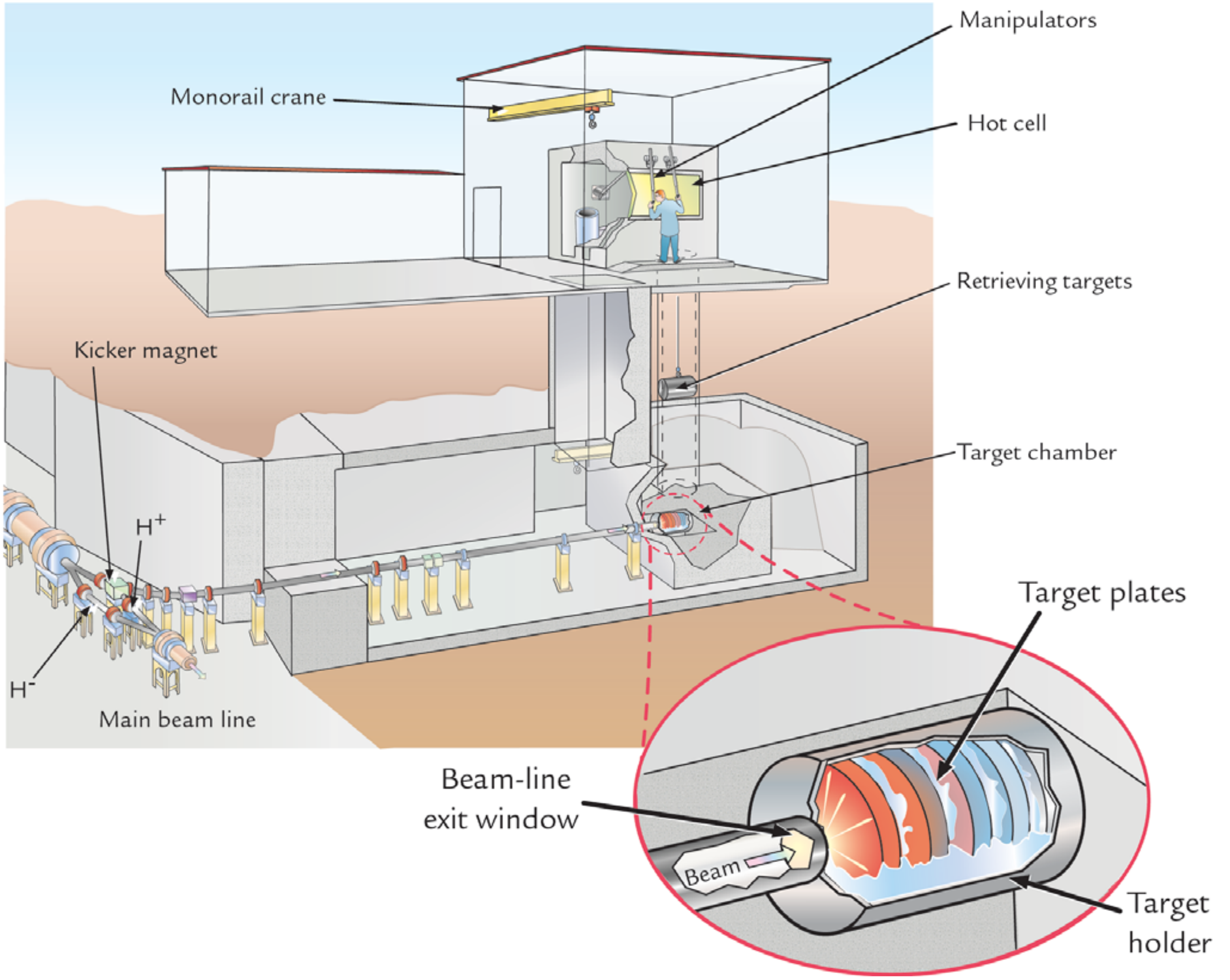


Fig. 1. *Artistic rendering of the IPF.*

irradiated targets to a processing facility where radioisotopes will be separated from the irradiated targets and prepared for distribution.

The IPF project, which will cost slightly less than $20 million, was first initiated in November 1998. In 1999, a detailed design of the IPF and equipment was completed and construction began in February 2000. The new IPF building was completed in January 2002. Installation of the beam line and special equipment is currently under way. The IPF is expected to become operational in 2003 after completion of the facility readiness assessment.

Innovative Target Insertion and Retrieval Operations

The LANSCE accelerator is made up of three components: an injector that accelerates a proton beam to 750-KeV, a drift-tube linac (DTL) that further accelerates the beam to 100 MeV, and a side-coupled cavity linac (SCCL) that finally accelerates the beam to 800 MeV. The region between the DTL and the SCCL includes a transition zone where a 100-MeV proton beam can be extracted from the existing main beam line (Fig. 1). A fraction of the 100-MeV proton (H^+) beam will be extracted by a new kicker magnet. The extracted beam will be transported through a new beam line to a radioisotope production target chamber located in the lower level of the new facility. (The undeflected proton beam will continue into the SCCL where it will be accelerated to 800 MeV for use in other beam lines.) The new beam line ends at the target chamber where the beam will pass through an exit window and irradiate the target assembly, which will consist of a stack of flat metal plates arranged in a holder along the horizontal beam center line (Fig. 1, inset). Spaces between the plates will be filled with flowing water coolant to prevent the targets from melting and to degrade the proton beam energy. The front plate in the target assembly will experience nearly the full 100-MeV beam energy, whereas plates further back in the stack will be irradiated at progressively lower beam energies. As the beam passes through the successive layers of plates and water, it will effectively slow to a stop in the last plate. The nuclear reactions needed to produce useful radioisotopes have resonances in the 20- to 100-MeV range. As such, several production reactions with different energies can be initiated simultaneously by using an appropriate array of target plates and water channels.

A remotely operated target transport mechanism will insert and retrieve targets through a vertical shaft between the target chamber in the lower level of the facility and a hot cell in the upper level. This mechanism will transport the target assembly between the target chamber and the hot cell and ensure that targets are in proper placement for irradiation. The hot cell will provide a shielded working area where radioactive targets can be remotely mounted, unmounted, and loaded into shipping casks using manipulators and other remotely operated tools. The hot cell is shielded on three sides and on the top with concrete and steel shielding, whereas the fourth side contains a shield door, which will provide personnel access to the interior of the hot cell when necessary. Certified casks will be used to ship irradiated targets from the IPF to the chemical-processing facility, which is located at another technical area at LANL.

Factors Affecting Radioisotope Production

When the proton beam impinges on a target plate, a small fraction of the protons interacts with the target to form product nuclei. Take, for example, the irradiation of zinc to produce copper-67, which is an important radioisotope used in lung cancer research and in monoclonal antibody labeling. (Monoclonal antibodies are pure, uniform, and highly sensitive protein molecules produced by genetic engineering techniques for use in medicine to diagnose and combat a number of diseases.) Sufficiently energetic protons will react with zinc-68 nuclei in the target, resulting in the absorption of one proton and the emission of two others. This reaction results in the formation of copper-67 nuclei. The factors that determine the amount of copper-67 produced in this reaction include (1) the number of zinc-68 atoms placed in the beam, (2) the number of protons per unit time that strike the target, (3) the probability that a proton will actually collide effectively with a zinc-68 nucleus and give rise to the desired nuclear reaction (i.e., the cross section), and (4) the duration of the bombardment. Maximizing all these factors produces the best yield of copper-67.

Protons that do not participate in the nuclear reactions are impacted in two important ways. First, the protons lose energy as they pass through the targets and the cooling water. Second, they are deflected from their incident path, resulting in a broadening of the beam. The new IPF will take advantage of the first phenomenon by configuring the target stack to give the desired energy range in one or more successive targets. The beam energy range in a target is an important factor in maximizing the probability of the desired nuclear reaction. Targets at the front of the stack will be used to degrade the beam energy to the desired levels for subsequent targets. In this way, several targets can be irradiated at different energies simultaneously, thus maximizing the efficiency of the facility. The new IPF target assemblies will be thick enough so that the beam energy will be degraded to zero within the last target in the assembly. With all of the beam energy deposited into the target materials, the target assembly must be cooled (as described above) to keep the targets from melting. The cooling is accomplished by circulating cooling water between the target plates. The thickness of the water channels is important not only in achieving effective heat transfer but also in obtaining the desired amount of beam energy degradation for subsequent targets.

One consequence of the deflection of protons noted above is that even a narrowly mono-energetic beam will acquire an energy spread. The extent of this energy spread will depend on the nature of the incident particles, the nature of the target material, the physical thickness of the target, and the depth of the beam in the target assembly. This beam-energy spread may limit the control that can be exercised over nuclear-reaction channels in targets located at the back end (low energy) of the target stack. Many factors must therefore be considered in relation to irradiating targets to yield useful quantities of radioisotopes. Beam energy, beam current, desired and undesired nuclear-reaction cross sections, target configuration and mass, and stopping power are all critical parameters. Ultimately, production yields from specific target configurations are best determined empirically. The new IPF will provide an important research capability for determining such yields.

With the construction of the new target-irradiation capability at LANSCE, LANL will continue its tradition of producing and distributing a rich variety of radioisotopes for medical, industrial, environmental, and other tracer applications.

Accelerator Systems for the Advanced Hydrotest Facility

J.A. Paisner, A. Jason, H.A. Thiessen (LANSCE Division Contacts)

The Advanced Hydrotest Facility (AHF) is an important future capability for the Department of Energy (DOE)/National Nuclear Security Administration (NNSA) Stockpile Stewardship program. The AHF will use pulses of relativistic protons to simultaneously penetrate, from many angles, dense fast-moving objects, thus providing three-dimensional very high-resolution radiographic motion pictures of these objects. Those images will give Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) the critical information necessary to assess the safety, performance, and reliability of our aging nuclear-weapons stockpile.

Capabilities of the Advanced Hydrotest Facility

Detailed requirements for AHF performance that supports certification are currently being refined within LANL in coordination with LLNL. The preliminary functional requirements that have been used for design are included in Table 1 below.

With these specifications, the AHF will provide measurements of the required resolution and accuracy to compare directly with calculated results from design codes used to simulate weapons implosions: density (and thus criticality), cavity shape, and mix. AHF system availability should allow an average of one experiment every two weeks; the only limiting factor will be firing-site activities.

Table 1. AHF preliminary functional requirements

Spatial resolution	< 1.0 mm
Time resolution	50 ns
Time coverage	75 μs (with 200-ns pulse-spacing capability)
Number of frames	>20
Number of axes	up to 12
Field of view	12 cm (at nuclear times) and 30 cm (for full view)
Beam angular acceptance	7 mrad (half angle)

Down-Selected Configuration Description

Initial AHF studies conducted in 2000 suggested many options for the accelerator configuration. The most promising ones were identified for further study and subsequently down-selected to a reference configuration (shown in Fig. 1) for entering the project's conceptual-design phase.

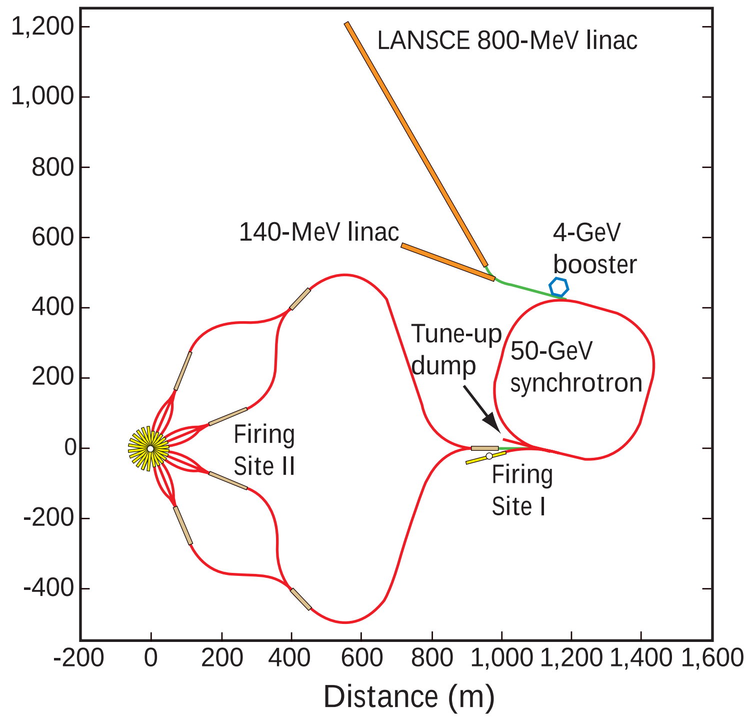


Fig. 1. *The accelerator beam-transport reference configuration.*

The baseline scenario uses the linear accelerator (linac) at the Los Alamos Neutron Scattering Center (LANSCE) to inject 2.5 x 10^{12} 800-MeV protons into a booster synchrotron. Alternatively, in a green-field scenario, a 140-MeV linac provides the input beam. The linac proton bunch is compressed and accelerated to 4 GeV in the booster, forming a single 100-ns bunch that is then transferred to one of the 24 buckets (acceleration slots) available in the synchrotron. After 20 such cycles (in 4 seconds), the main synchrotron accelerates the accumulated bunches to 50 GeV, compressing each of them to 20 ns. The beam is then ready to be delivered to an experiment with a total impingement of 3×10^{13} protons on the object per cycle.

Beam bunches are individually extracted from the 50-GeV synchrotron by fast kicker magnets. A typical time sequence would be 10 pulses extracted with 10-μs spacing between adjacent pulses and the remaining 10 pulses at shorter 200-ns intervals to observe the accelerating culmination in the last phase of an imploding object. The bunches can be sent alternatively to Firing Site I (FS-I) or, via an elaborate transport system, to Firing Site II (FS-II).

In the project's staged approach, FS-I will be constructed first to provide needed capability for the weapons designers and to act as a test bed for later designs of FS-II. The beam sent to FS-II is split into 12 equal parts that converge on the site at 15° angular intervals. Splitting occurs when a beam pulse impinges on the edge of a thin septum plane formed by thin (50-μ-diam), parallel wires with opposing electric fields on each side. This 3-m-long wire plane produces a slight angular spread between the beam halves, which are further transversely deflected along a 40-m distance by a series of dipole magnets to produce a separation of 1 m. Eleven such splitters and a total 1185° of dipole bends are needed for the selected configuration that requires nearly 6 km of tunnel. Transport magnets are pulsed to maintain acceptable peak-power limits.

For the LANSCE site, the synchrotron is located some 102 m beneath the linac, and the transport system passes 15 m underneath East Jemez Road to FS-II in Mortandad Canyon. A topographic view of the *in situ* facility is shown in Fig. 2. A green-field site on level ground would require some 15 m of earth cover for shielding.

The basic configuration of FS-II and the lens systems that will provide imaging and material discrimination were given in the 2000 LANSCE activity report (http://lansce.lanl.gov/news/ARtabofContents.htm).

Trade-off Studies

The several options selected for the final down-select configuration in the trade-off studies included the following:

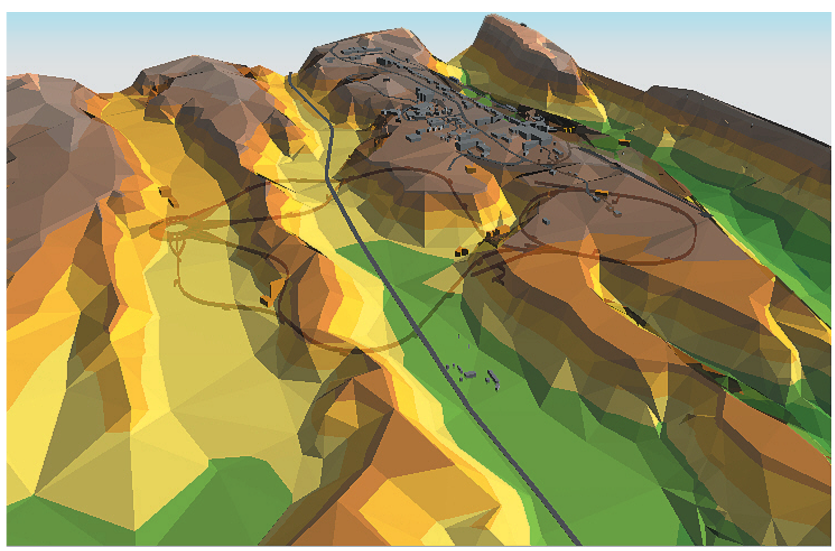
Cycle time (i.e., time between synchrotron cycles) between 10 and 100 seconds (choice between ease of tuning versus power consumption). An intermediate cycle time of 25 seconds was chosen. This corresponds to a manageable average power consumption of 8 MW for the facility magnets. Peak magnet power, unaffected by cycle rate, is about 30 MW.

Power-source selection (energy storage or direct use from the power grid to provide the high-peak power required). A flywheel/motor generator option was chosen to avoid the many uncertainties of new power-line construction and supply.

Injection into the synchrotron (use of a booster or not). The booster option was chosen as most compatible with a green-field site because it would avoid the need for a high-energy linac. At LANSCE, the booster would provide the higher charge/pulse required for FS-II, allow a smaller synchrotron beam aperture, and could be omitted for an initial stage.

Synchrotron-dipole magnets (use of an existing magnet design, that of the main injector at Fermi National Accelerator Laboratory [Fermilab], or a custom design). The Fermilab magnets were considered very adequate without much adaptation needed; their use would eliminate schedule and cost burdens.

Transport-line-arc dipoles and quadrupoles (with superconducting or normal conducting magnets). Using superconducting magnets would shorten tunnel lengths by



↑ ***Fig. 2.*** *View (from the east) of the in situ facility for the LANSCE TA-53 option. The accelerator and transport system are well underground. The booster is not shown in this figure.*

2 km and decrease the area of transport lines by a factor of 2. Cost advantages of either option could not be resolved and peak-power use was not dramatically smaller for the superconducting option. Normal conducting magnets were chosen to eliminate the development needed for superconducting magnets and to focus on performance areas.

Synchronous or asynchronous transport (whether or not all paths in the beam transport should have the same length). Different path lengths (asynchronous option) would lead to a substantially smaller transport system but would require the extraction of two pulses from the 50-GeV synchrotron at different times to achieve simultaneous pulse arrival at the object. This option would greatly limit pulse-pattern flexibility. The synchronous option that decouples the accelerators from the transport line was selected.

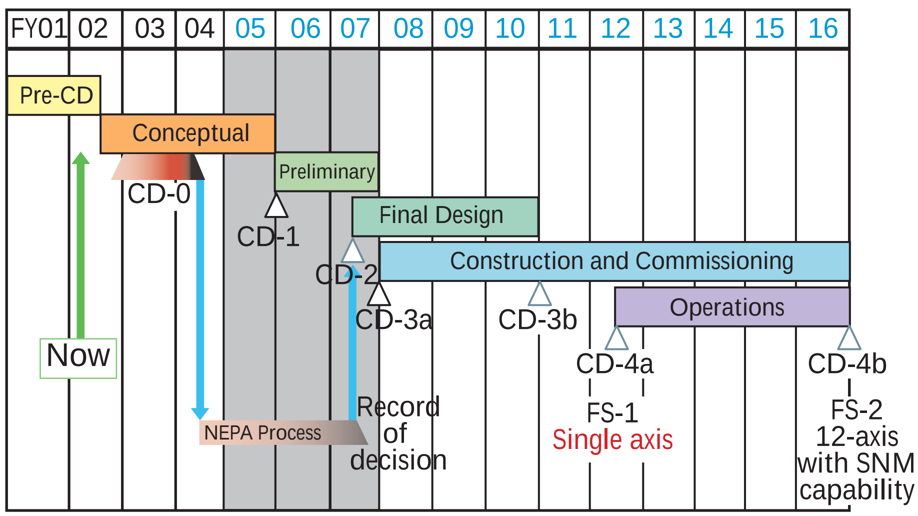
Lens quadrupoles (superconducting or normal conducting magnets). Normal conducting lens magnets meeting project requirements would need large peak powers (~ 80 MW). Estimates showed that the cost savings with superconducting magnets would not be large. However, despite the need for substantial development, the payoff in the performance of superconducting magnets was convincing in their selection.

Project Reviews

The AHF project holds quarterly reviews on the project status and on technical progress and issues. Smaller internal reviews are held on specific aspects of the project at an increasing rate. In particular, contracting institutions—mainly the Massachusetts Institute of Technology (MIT), Brookhaven National Laboratory (BNL), Fermilab, and Indiana University Cyclotron Facility—and other entities within LANL are asked to visit, and critical internal reviews are held. A review committee was formed, called the Beam Technical Advisory Group (BTAG), to obtain external input on the accelerator efforts. The BTGA, chaired by Dr. William Herrmannsfeldt from the Stanford Linear Accelerator Center, consists of eight external members with extensive accelerator-project experience. The first BTAG review was held for two days in the fall of 2001 on the accelerator and beam-transport design. The written BTGA review was very complimentary of the depth and quality of the presentations and the design.[1]

Project Schedule

The envisioned fiscal year (FY) 2007 completion date has been extended. This delay was driven by several factors that include unavailability of capital funds until FY2005 and limitations placed on construction funds in the following years. Additionally, weapons-certification methodology underpinning the transition to an AHF needs development time and additional resources. Conceptual design (CD-0) is expected to start in summer 2002 and continue through FY2005 with final design work beginning in mid FY2007. With this schedule, the synchrotron will be completed and FS-I will be commissioned by mid FY2012. The twelve-axis firing site (FS-II) will be commissioned by the end of FY2016 and will have special-nuclear-material (SNM) capability. These and other project events are shown in Fig. 3.



↑ ***Fig. 3 .*** *Current AHF project schedule. (The symbol Δ depicts major DOE/NNSA critical decision points.)*

Project Engineering Design and Development

Several portions of the project require Engineering Design and Development (EDD). Accordingly, the project has initiated several EDD activities that focus on early development of items that have technical or schedule risks.

Accelerator magnets and radio-frequency (rf) system. The accelerator and beam transport together require over 2,000 magnets. Steps were taken to simplify their design and construction by adapting designs used in other accelerator projects. Nonetheless, with projected funding profiles, the synchrotron magnets lie on the project critical path. A special effort is directed toward development of the accelerator magnets that will include work with Fermilab. The synchrotron also requires EDD for the fast-extraction-kicker modulator needed to achieve short rise times (< 100 ns) and large magnetic impulses to extract beam from the synchrotron on demand. A cooperative effort with LLNL has been started and shows promising results in initial work based on earlier designs. An additional effort has begun in development of the rf system that provides the energy for acceleration of beam in the synchrotron and booster.

Imaging magnets. The superconducting quadrupole magnets used in the imaging lenses are large and unique structures. For the large field-of-view lines, the diameter of the beam bore is 19 in., and the magnet is 4 m long with a gradient of 10.4 T/m. Thirteen of these magnets must be ready for FS-I and an additional 52 for FS-II. Additionally, 104 smaller-bore (9-in.) magnets are needed for FS-II. Although conceptually similar to other (smaller) accelerator magnets, the imaging magnets require substantial development, particularly because their coils may need to be made from difficult-to-work materials that can withstand the radiation heating from the beam-target interaction. This development effort has begun at other institutions (MIT, BNL, and Fermilab) having extensive facilities and expertise for the development of prototype magnets.

Firing sites and vessels. Defining the development of the multiple containment/confinement vessels at the firing sites will also impact the detailed facility design and procedures. Because high pressures and shock waves will be encountered in tests, strong vessels will be required to avoid leakage of hazardous materials and damage to surrounding equipment. On the other hand, the vessels must look thin to the proton beam to minimize blurring caused by scattering from the vessel walls. Work on vessel mechanical engineering, clean-up techniques, and materials handling is proceeding with several laboratory groups. An effort is under way at LLNL to develop hybrid, composite fiber-wrapped vessels that minimize beam scattering by the vessel walls.

Summary

The AHF project is progressing toward conceptual design. Many technical choices have been delimited by the extensive use of trade studies, and a "best" architecture flexible enough to meet requirements has been chosen. A detailed review of many project areas was conducted by an expert external advisory group, which endorsed the technical solutions adopted by the project. A strong EDD program has been set up to address critical items. Although funding projections have extended the AHF deployment schedule, more time is now available to resolve project issues before starting line-item work. With the prospect of creating a premier facility for stockpile stewardship, project staff members have found their activities technically challenging and rewarding.

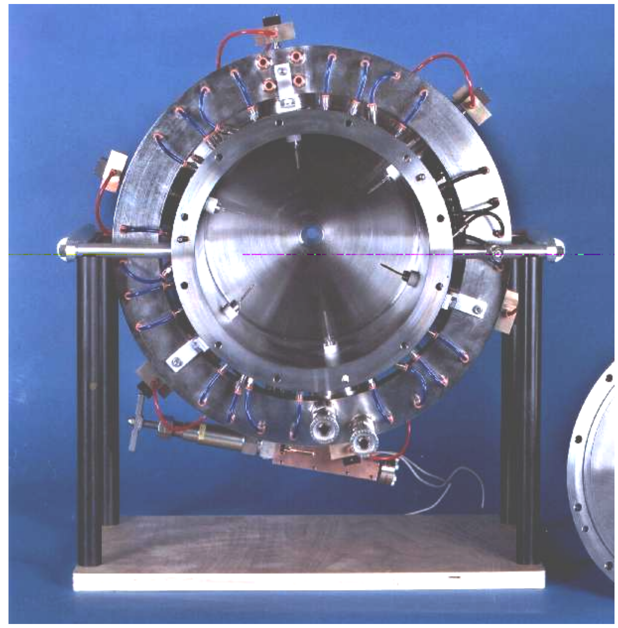
References

1. Final report of the review meeting of the Beam Technical Advisory Group (October 26, 2001); Advanced Hydrotest Facility reports AHF-CP-01-014 and AHF-CP-01-020.

Short-Pulse Spallation Source Enhancement Project

P.S. Lewis (LANSCE Division)

The Short-Pulse Spallation Source Enhancement Project is significantly upgrading Los Alamos Neutron Science Center (LANSCE) capabilities by increasing the neutron source intensity and by constructing additional neutron-scattering spectrometers. Because the facility improvements will support both the defense and basic research communities, this project is jointly funded by the Department of Energy Defense Programs (DP) and Office of Science (SC). DP is supporting accelerator improvements, which will increase the 800-MeV proton beam current delivered to the Lujan Neutron Scattering Center (Lujan Center). SC is supporting the design and construction of new neutron-scattering spectrometers at the Lujan Center.



↑ ***Fig. 1.*** *Photo of the new ion source designed and fabricated for LANSCE by LBNL.*

Accelerator Enhancement

The primary technical goal of the upgrade is to increase the average proton current delivered to the Lujan Center spallation target to 200 µA at a 30-Hz repetition rate to provide 160 kW of power to the target. To achieve this performance goal, the following major modifications to the LANSCE accelerator facilities are being carried out.

- The Proton Storage Ring (PSR) is being upgraded to handle higher accumulated charge levels. The upgrade includes a redesigned radio-frequency (rf) buncher and modifications to the ring and 1L transport line to control instabilities and to minimize slow beam losses.
- A brighter H^- ion source for the accelerator is being developed in collaboration with Lawrence Berkeley National Laboratory (LBNL). In addition, the injector's 80-kV accelerating column and its high-voltage power and control systems are being upgraded to accommodate the new source.

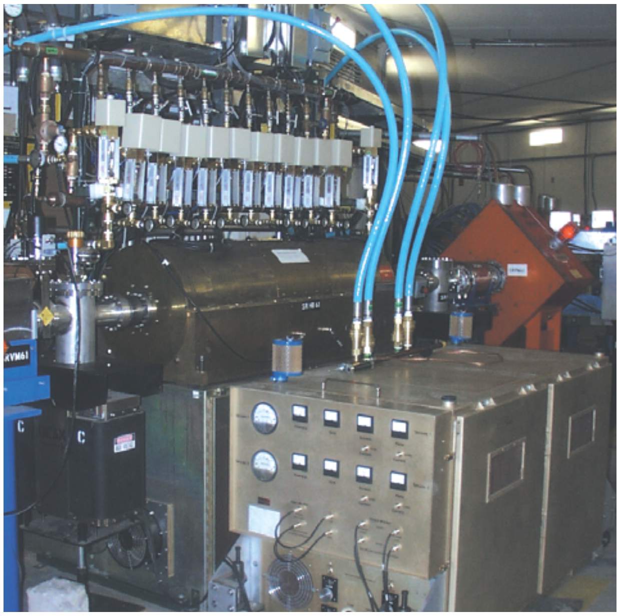
Ion Source and Injector Upgrade. The ion source (Fig. 1) and injector upgrade includes

- development and fabrication of axial proof-of-principle, prototype, and final production sources at LBNL with a technical goal of 20 to 40 mA H^- current at an emittance of 0.4 to 0.8 π mm-mrad, 95% normalized;
- construction, instrumentation, and validation of the Ion Source Test Stand (ISTS) at Los Alamos National Laboratory;
- development of a new 80-kV column to accommodate higher source current;
- upgrade of the injector high-voltage power and control systems to accommodate the new source and column;
- system testing prior to installation; and
- installation and commissioning.

Development and fabrication of the ISTS source, column, and high-voltage power and control systems have been completed. In 2002, all of the hardware will be installed on the ISTS for long-term systems testing.

Proton Storage Ring Upgrade. The PSR upgrade includes

- a redesign and refurbishment of the rf buncher to increase its peak voltage from 12 to 18 kV (peak) and improve its reliability (Fig. 2),
- upgraded power and water utilities in the PSR,
- extensive PSR testing to identify means of controlling the PSR instability at accumulated charge levels of 6.7 µC and above,
- installation of multipole magnets and inductive elements in the PSR to control transverse instabilities,



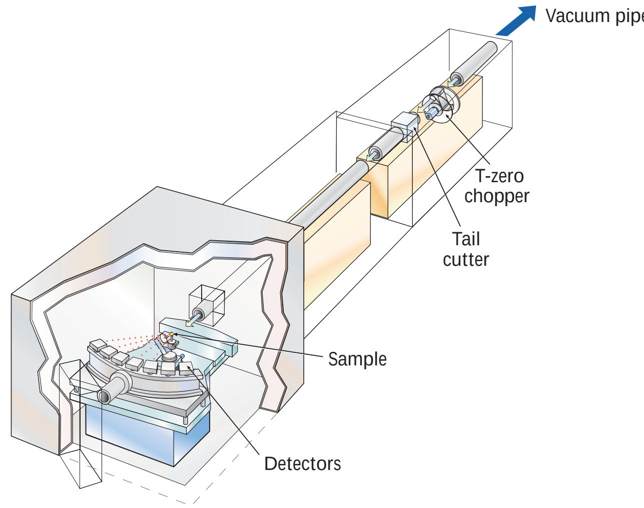
↑ *Fig. 2. Refurbished rf buncher in the PSR.*

- titanium nitride (TiN) coating of key PSR vacuum chamber components to reduce electron multipactoring, and
- improvements to the 1L transport line to reduce losses that contribute to background radiation levels in experimental room ER-1 at the Lujan Center.

The buncher and utilities upgrades have been successfully completed. Tests have demonstrated control of the PSR instability to levels of up to 10 μC of accumulated charge. The design, installation, and commissioning of the PSR multipoles and inductors were successfully completed. The TiN-coated components are ready for installation. Design of the 1L improvements has been completed.

Spectrometer Development

The spectrometer development project has added three neutron-scattering instruments to the Lujan Center. The individual instruments were designed and constructed by collaborative spectrometer development teams involving participants from federal laboratories, universities, and industry. One of the instruments, the Protein Crystallography Station (PCS), is a structural biology spectrometer funded by the Office of Biological and Environmental Research. The Office of Basic Energy Science funded the remaining two instruments: the Spectrometer for Materials Research at Temperature and Stress (SMARTS) and the High-Pressure Preferred Orientation Spectrometer (HIPPO).



↑ *Fig. 3. Protein Crystallography Station beam layout. In ER-1, a composite T_0/T_1 chopper and a (proposed) tail-cutting device remove unwanted high- and low-energy neutrons, thus optimizing the neutron beam for high counting rates and low backgrounds at reasonable instrument resolutions. The vacuum pipe is tightly surrounded by heavy shielding until it reaches the sample position where the shield opens up to a large cave in ER-2. In the cave, neutrons interact with atoms in the crystal sample, are scattered, and are detected by a large two-dimensional cylindrical area detector. A k-circle goniometer moves the crystal and detector between about 30 different orientations. This feature enables all planes in the crystal to be brought into an orientation that will produce diffraction spots.*

Protein Crystallography Station. The PCS is a neutron diffractometer designed for structural biology (Fig. 3). The instrument is located on flight path (FP) 15 viewing a partially coupled high-intensity water moderator with beryllium reflector. The instrument includes a large position-sensitive two-dimensional detector, designed and fabricated by Brookhaven National Laboratory, that allows horizontal and vertical scans. Construction was completed in 2001. For more information on the PCS, see *Protein Crystallography Station—Commissioned and Ready for Users* in this report, p. 140.

Spectrometer for Materials Research at Temperature and Stress. SMARTS is a powder diffractometer optimized to measure strain on both very large and small samples within a variety of sample environments (Fig. 4). The instrument has two principal modes of operation—strain scanning and material testing. In the strain-scanning mode, SMARTS is capable of measuring stress distributions in engineering components and other samples. In the material-testing mode, SMARTS can carry out measurements of materials under load, at high temperatures, and in controlled atmospheres. SMARTS is located on FP2 viewing a high-resolution water moderator. The instrument includes a neutron guide to enhance the flux

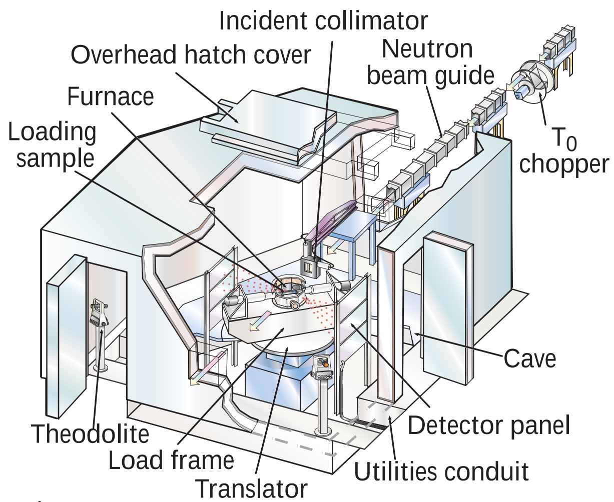


Fig. 4a

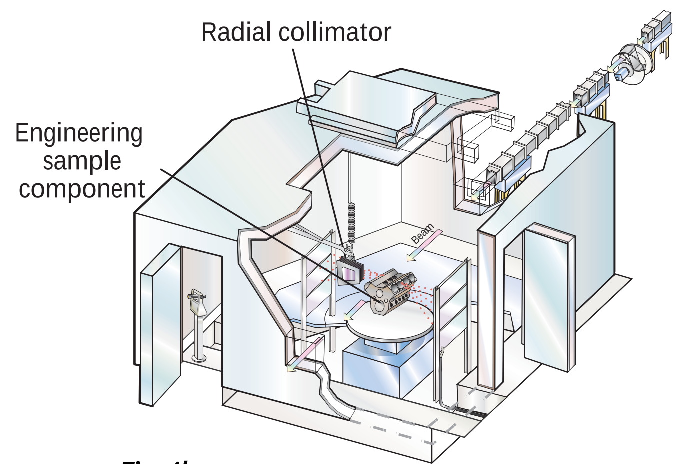
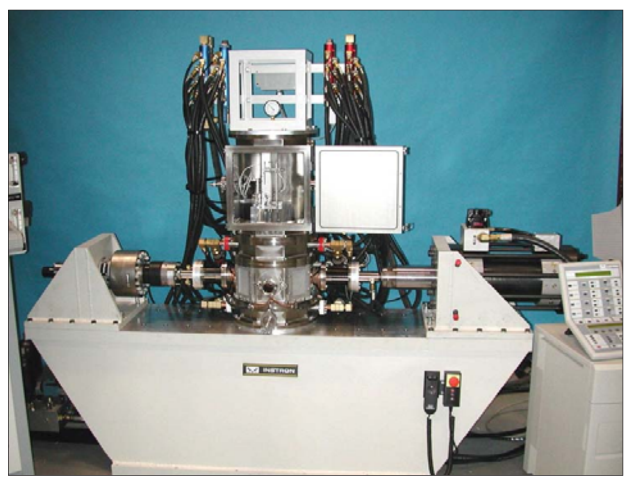


Fig. 4b

↑ *Fig. 4 . SMARTS beam layout. Neutrons from the moderator pass through a series of collimating apertures before entering the neutron guide. In ER-1, a break in the guide accommodates a T_0 chopper, which removes fast neutrons and gamma flash that would otherwise contribute unwanted background. Slow thermal neutrons continue down the guide to the entrance of the SMARTS cave. On exiting the guide, neutrons pass to the center of the cave where some are scattered by the crystal structure of the sample to the detectors. Samples or ancillary systems are placed directly on the translator, which can accommodate up to 1,500 kg, move in three orthogonal directions, and rotate about a vertical axis. Theodolites provide a precise optical triangulation and alignment capability for equipment or samples. Fig. 4a illustrates the load-frame-furnace suite in place. Note that there is no collimation between the sample and the detector. Fig. 4b shows a radial collimator between the detector and a generic engineering sample. When used with the incident collimation, selection of an appropriate radial collimator defines a sampling volume for spatially resolved measurements. (Note: Beam-line shielding is not shown.)*

↑ ***Fig. 5.*** *View inside the SMARTS cave, showing the translator mounted in the pit, one of the two banks of ^{3}He detector panels, and the incident beam collimation.*



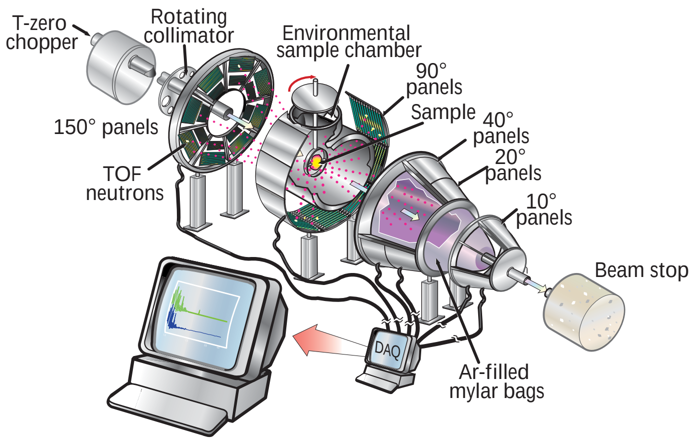
↑ ***Fig. 6.*** *Load frame and furnace set provides tension and compression up to 40,000 lb and temperatures up to 1,500°C.*

on the sample, the capability of accommodating a sample with a total mass of at least 500 kg, and the capability of carrying out *in situ* strain measurements on samples at 180 kN and at 1,500°C.

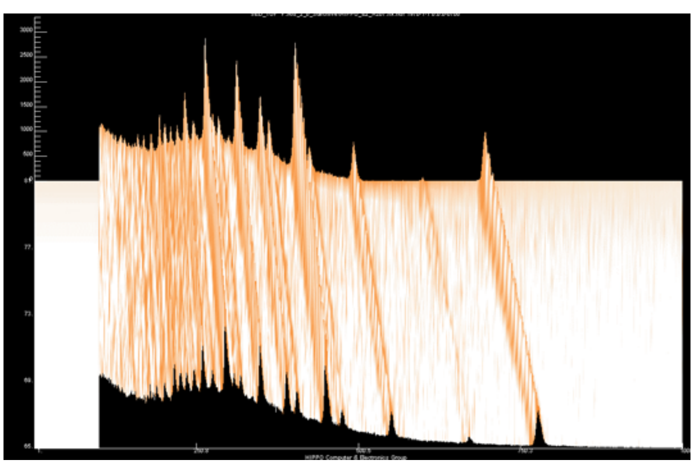
Fig. 5 shows a view of the translator mounted in the pit, one of the two banks of ^{3}He detector panels, and the incident beam collimation. Fig. 6 shows the load frame and furnace. Construction was completed in 2001. For more information on SMARTS, see *SMARTS—A New Spectrometer for Studies of Engineering Materials* in this report, p. 144.

High-Pressure Preferred-Orientation Spectrometer. HIPPO is a high-intensity powder diffractometer designed for texture measurements (Fig. 7). HIPPO has the capability to study samples at high pressure and high and low temperatures. The instrument is located on FP4 viewing a high-intensity water moderator, and it includes detector banks at (nominally) 150°, 90°, 40°, 20°, and 10° (1,384 detectors, 4.6 m^2) and a sample changer capable of rapid interchange of samples.

A diffraction from a nickel test sample is shown in Fig. 8 below. Figs. 9 and 10 are photos of the HIPPO construction. Construction of HIPPO was completed in 2001. For more information on HIPPO, see *HIPPO—A New High-Intensity, Multiple-Environment Neutron Diffractometer* in this report, p. 146.

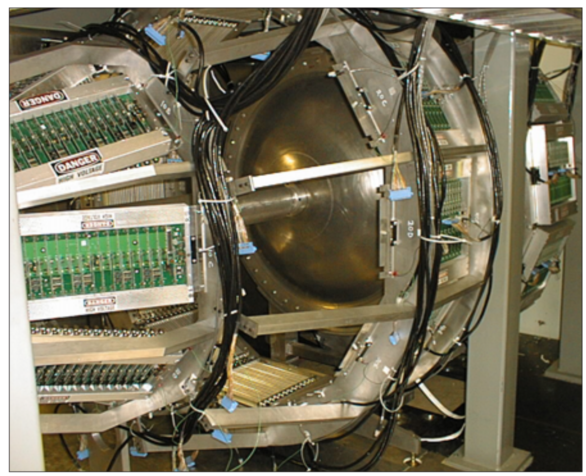


↑ ***Fig. 7.*** *Exploded view of HIPPO showing sample chamber surrounded by five conical three-dimensional rings of ^{3}He detector tubes in 10 atm. A white beam made up of pulsed neutrons of different energies (entering from the left) travels down a collimator to a chopper that cuts out very fast neutrons, allowing only slower thermal neutrons to continue down the FP to the bulk material contained inside a 29-in.-diam sample chamber. The neutrons interact with the lattice (crystal) structure of the bulk material, diffract off, and impinge on the detectors. Neutron diffraction is measured to ascertain how the energies or momentum of the neutrons changed after interacting with the atoms. (Note: FP and cave shielding are not shown.)*



↑ ***Fig. 8.*** *HIPPO diffraction pattern from a nickel test sample. This figure shows Bragg peaks from time-of-flight data taken from a nickel test sample. Data were taken from sixteen detector tubes on one of the HIPPO 90° panels.*

↑ ***Fig. 9.*** *Photo of the HIPPO sample chamber being installed in its cave.*



↑ ***Fig. 10.*** *View inside the HIPPO cave, showing the sample chamber, detector frame, and detector panels. Each detector panel contains an array of ^{3}He tubes, along with the supporting electronics and high-voltage power supplies.*

LANSCE Switchyard Kicker Project

D.H. Fitzgerald, M.S. Gulley (LANSCE Division)

A project that has recently been in the planning stage received funding in July 2001 to design and implement a new capability for beam delivery at the Los Alamos Neutron Science Center (LANSCE). The Switchyard Kicker project, as it is known, will significantly enhance all programs that are served by the H^- beam.

The LANSCE beam switchyard (Fig. 1) is used to direct H^- beams from the 800-MeV linear accelerator (linac) into two beam lines: Lines X and D. Beams directed into Line D are sent to the Weapons Neutron Research Facility (WNR) and to the Proton Storage Ring (PSR). Beam extracted from the PSR is normally sent to the Lujan Neutron Scattering Center (Lujan Center) target, but can also be delivered to WNR. Beams sent to Line X are delivered to the proton-radiography (pRad) and ultra-cold-neutron (UCN) areas. (The switchyard can also be used to deliver protons to Area A via Line A.)

Simultaneous delivery of the H^- beam to Lines X and D is not possible at present. Generally, a few hours are required to switch the H^- beam from Line D to Line X. As a result, delivery of the beam to all users is interrupted during this transition period.

Motivation and Benefits

The switchyard kicker system will enable simultaneous, uninterrupted beam delivery to Line D (PSR, Lujan Center, and WNR) and delivery on request of a "tailored" H^- beam pulse to Line X (pRad or UCN). The requested beam pulse will be diverted from the 100-Hz beam normally delivered to WNR.

The switchyard kicker system will dramatically improve beam availability to all programs served by the LANSCE H^- beam. Beam availability to the experimental programs at the Lujan Center and WNR will increase by 25%, and beam availability to the pRad program will increase five-fold. This large increase in beam availability to Line X also provides the basis for an experimental program in UCN research.

The switchyard kicker system eliminates the need to retune the accelerator to accommodate varying beam intensities and time structures. This stable accelerator operation at fixed beam intensity yields more reliable beam delivery for all programs and reduces time and resources needed for beam retuning. In addition, it will enhance the safety of activities involving high explosives (HE) by relieving the time pressure associated with the accelerator schedule.

Technical Requirements

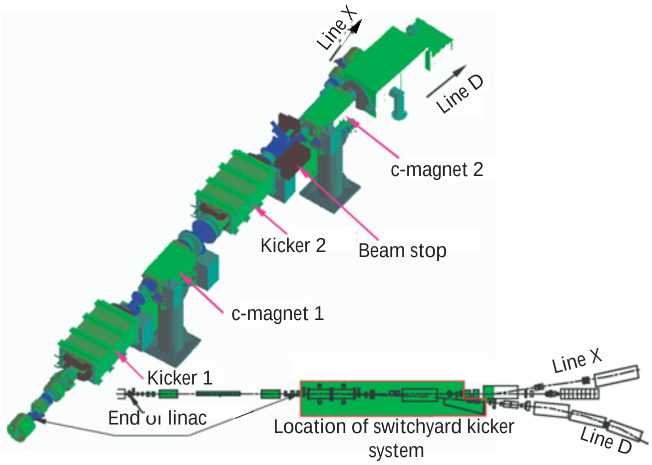
The kicker system will be capable of continuously delivering full-beam macropulses at a repetition rate of 1 to 20 Hz to Line X. The kicker-magnet response time is 8.3 ms, which is the time between beam macropulses at a linac repetition rate of 120 Hz. The kicker system has the capability of delivering a single macropulse on request, and it preserves the capability to operate in all the other existing modes. In particular, operation does not impact H^- beam delivery to Line D, other than increasing beam availability to the Lujan Center and WNR programs.

The technical requirements listed below have been defined, reviewed, and accepted by all stakeholders.

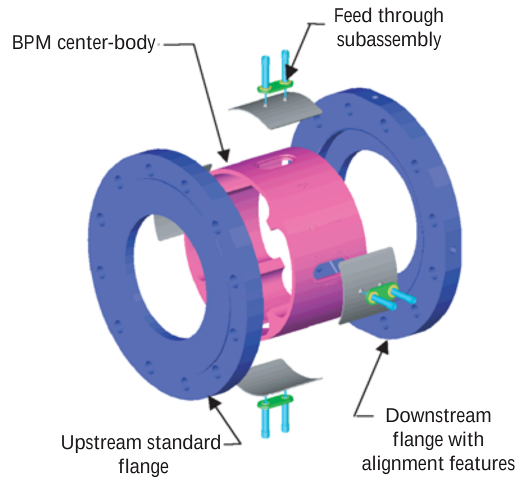
- The pRad program requires a beam intensity of 2 to 3×10^8 protons per 5-ns micropulse and a range of repetition rates from a single macropulse to 8 Hz. The required time structure is a train of 5-ns micropulses with predetermined spacings. The requirement for maximum pulse-to-pulse variation of beam centroid at the diffuser is 2 mm or less.
- The UCN experiments and the future UCN program require a beam energy of 800 MeV and a beam intensity of 5 μC per macropulse. The required time structure ranges from 1 to 8 pulses in 1 second or less, repeated every 10 seconds. The requirement for maximum pulse-to-pulse variation of beam centroid is 2 mm or less.
- The requirements for injection into the PSR impose a limit of approximately one part in 10^4 on the regulation of the magnetic fields for the bending magnets used to deliver beam to Line D.

Description

A design that satisfies or exceeds these requirements has been completed. A detailed, three-dimensional design layout has been completed, as shown in Fig. 1. The system comprises two pulsed magnets (kickers); two c-magnets, which operate in direct-current (dc) mode; beam diagnostics, including new beam-position monitors (BPMs); a revised vacuum system; and enhancements to the controls hardware and software. The c-magnets deflect the beam into Line D for delivery



↑ *Fig. 1. Three-dimensional layout for the switchyard kicker system. Also shown in the plan view is the location in the existing switchyard where the system will be installed.*



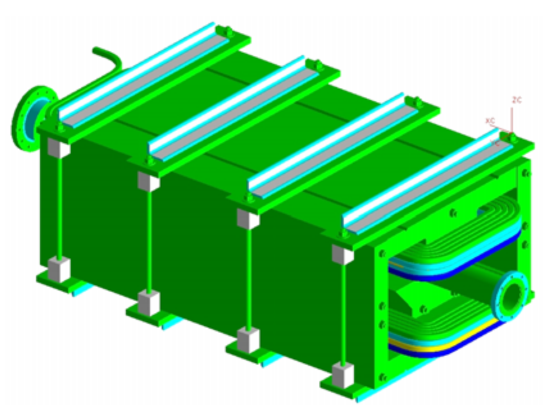
↑ *Fig. 3. Exploded view of the BPM-sensor design. Three identical BPMs will be used in the switchyard kicker system.*

to the PSR, Lujan Center, and WNR. When fired, the two kicker magnets counteract the bend of the first c-magnet, sending the beam straight ahead into Line X to either pRad or UCN.

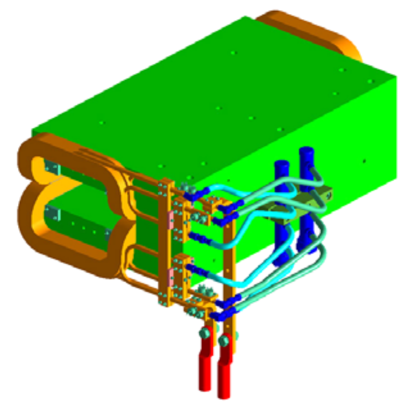
The design focuses on risk reduction and cost efficiency. The kicker magnets and modulators will be nearly exact copies of existing units that have proven to be highly reliable in the PSR-injection line. A solid model rendering of the design for the kicker magnets is shown in Fig. 2.

An existing dc power supply will be upgraded for use with one of the c-magnets. The project also has both technical and cost-savings benefits in adapting an existing design for the BPMs. The design for the BPM sensor is shown in Fig. 3.

The design for the c-magnets is similar to that for magnets in wide use at LANSCE, and the field quality is



↑ *Fig. 2. Three-dimensional drawing of the kicker magnets.*



↑ *Fig. 4. Three-dimensional drawing of the c-magnets.*

sufficient to preserve the beam quality required for PSR injection. A three-dimensional drawing of the magnet design is shown in Fig. 4.

Schedule

A resource-loaded project schedule and a detailed cost estimate have been completed for the project. Detailed designs and specifications are complete for all magnets, the kicker modulators, and the power supplies for the c-magnets.

Fabrication and procurement of the major components will be complete by August 2002. Component testing is scheduled for completion by October 2002, with installation occurring during the planned beam outage beginning January 2003. The system will be commissioned by May 2003.